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Prieto

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[54] **DATA COMPRESSION SYSTEM, METHOD, AND APPARATUS**

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[51] **Int. Cl.**[6] **G06K 9/36**; G06K 9/46; G06K 9/38

[52] **U.S. Cl.** **382/232**; 382/235; 382/248; 382/251; 382/253

[58] **Field of Search** 382/232, 233, 382/239, 235, 248, 254, 260, 276, 240, 275, 251, 261; 348/395, 398, 403, 408, 417, 418; 358/426, 261.3, 432, 433

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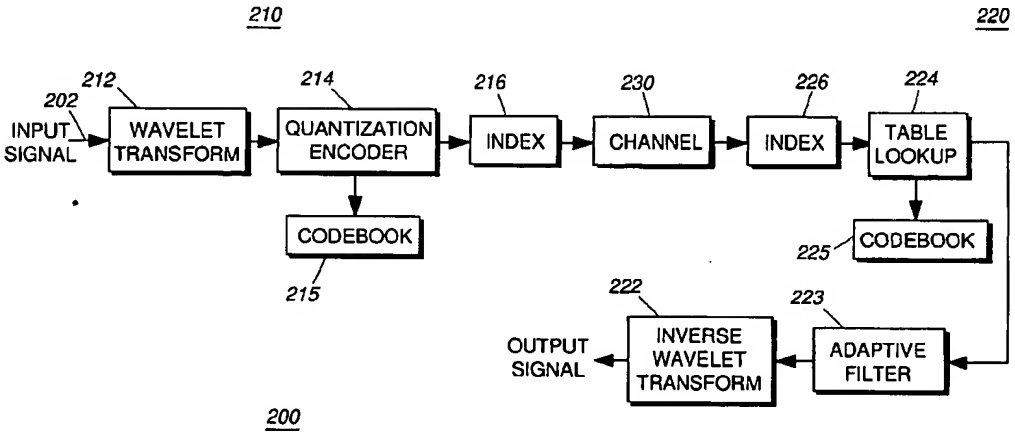
Attorney, Agent, or Firm—Val Jean F. Hillman; Barbara R. Doutre

[57] **ABSTRACT**

A data compression system **200**, method, and apparatus **214** employs an encoder **210** optimized to decorrelate and make independent from the original signal **202**, the quantization noise produced during signal compression. The proposed system **200**, method, and apparatus **214** supports high degrees of signal compression, which in turn leads to lower computational complexity and improved performance. Because the quantization noise produced during signal compression is made independent from and non-orthogonal (i.e., uncorrelated) to the original signal **202**, enhanced filtering is achievable, which in turn leads to improvements in the signal-to-noise ratio (SNR) of the decoder **220**.

39 Claims, 12 Drawing Sheets



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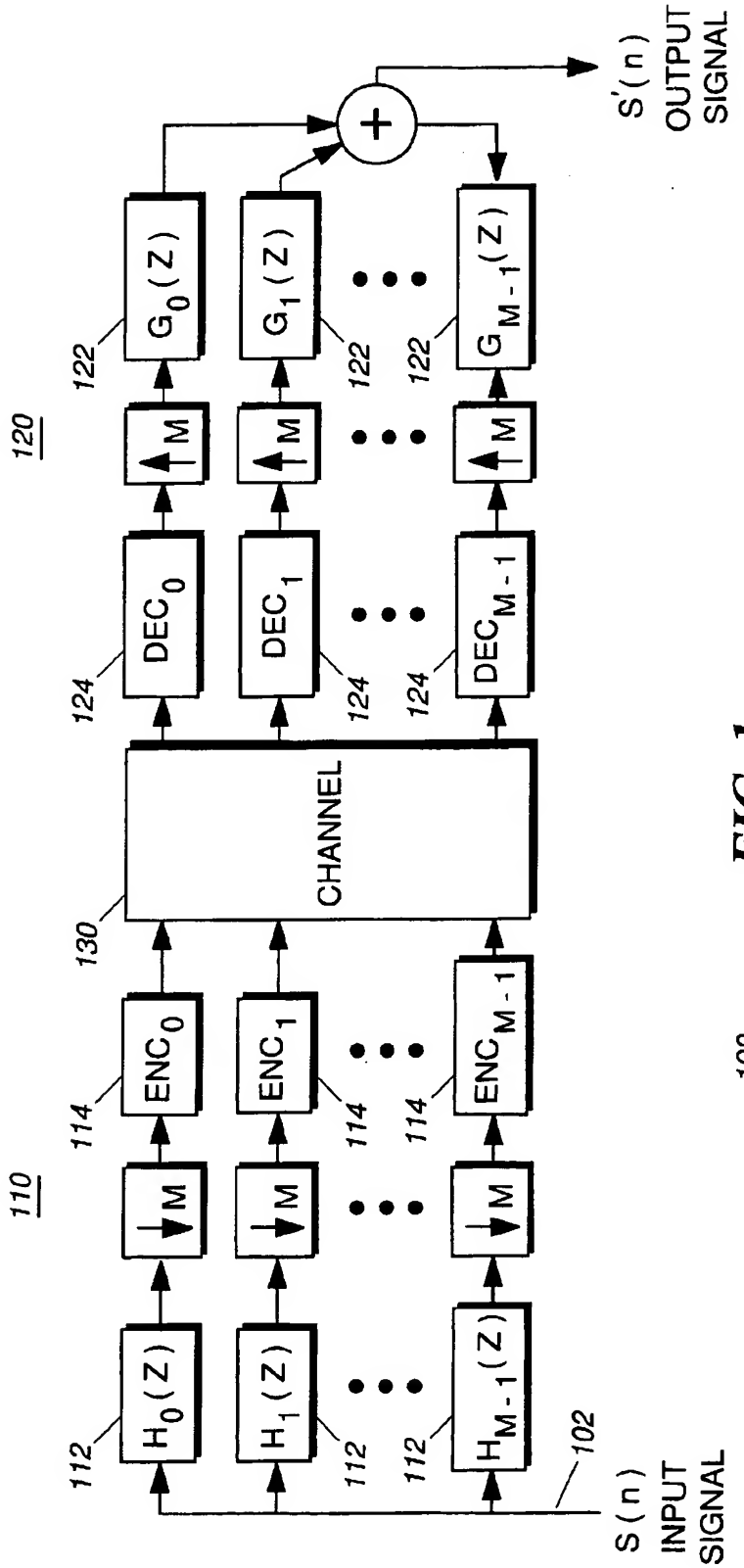


FIG. 1
(PRIOR ART)

100

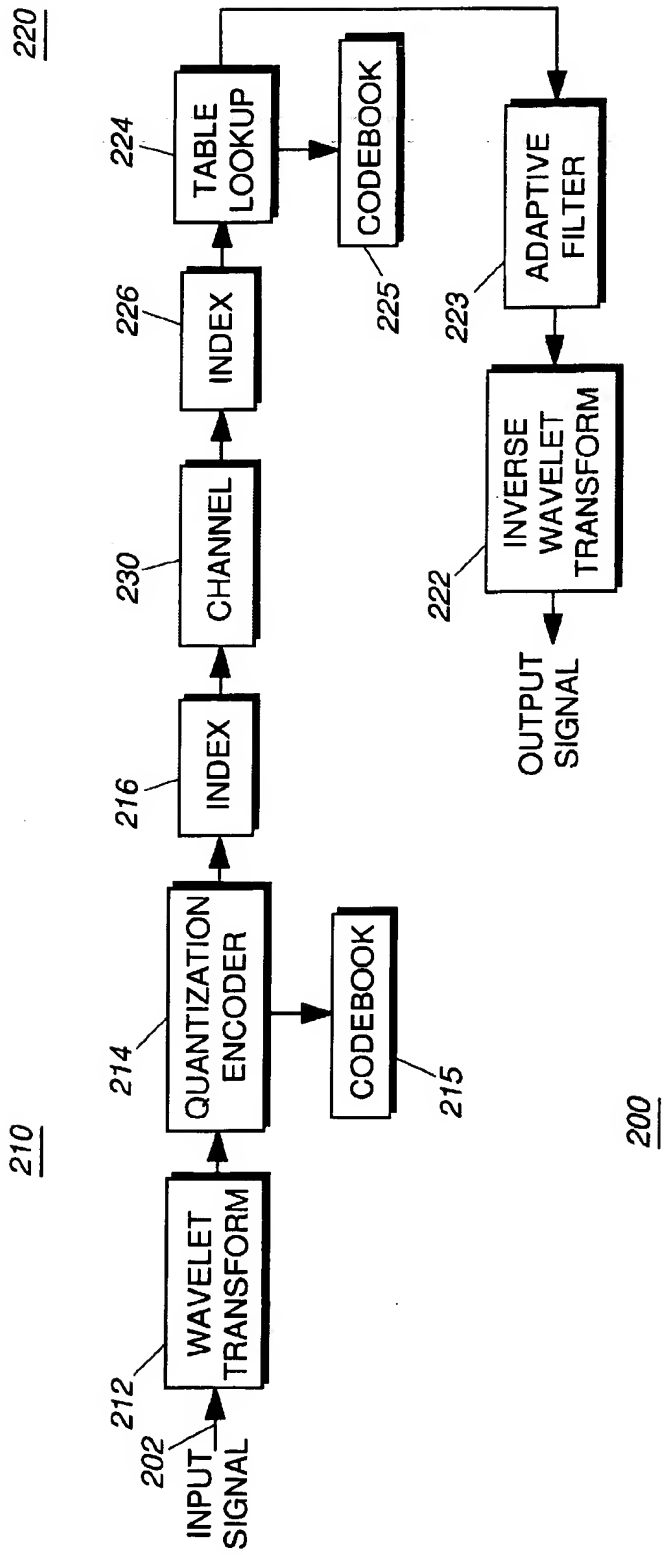

220
224
TABLE LOOKUP
CODEBOOK
225
226
INDEX
223
ADAPTIVE FILTER
230
CHANNEL
222
INVERSE WAVELET TRANSFORM
216
INDEX
OUTPUT SIGNAL
214
QUANTIZATION ENCODER
CODEBOOK
215
210
200
212
WAVELET TRANSFORM
202
INPUT SIGNAL

FIG. 2

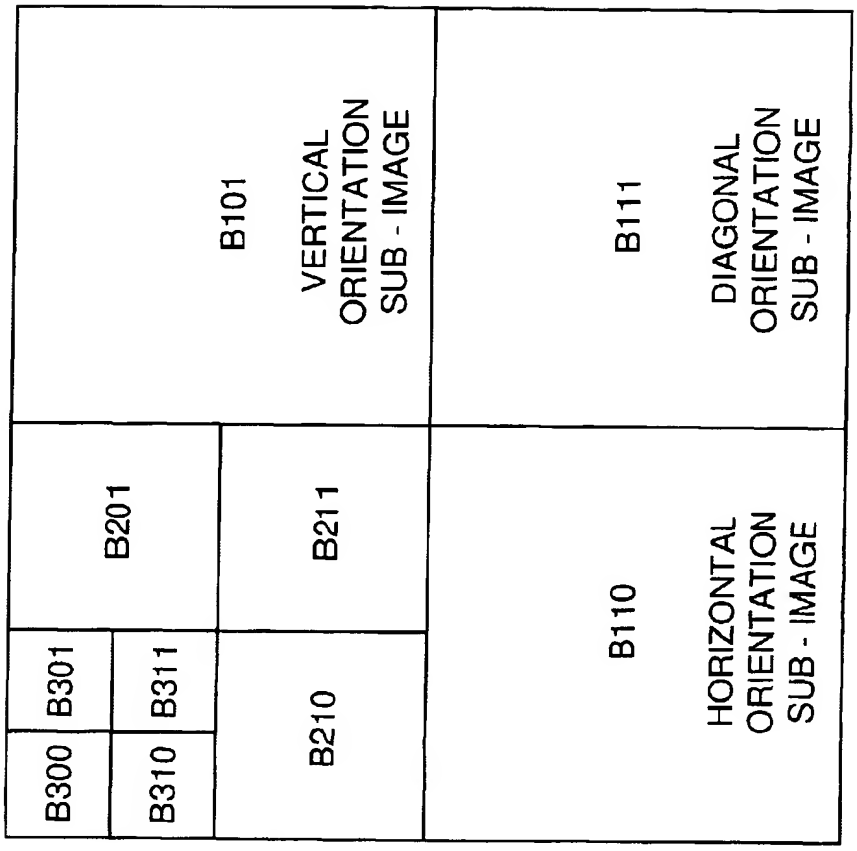
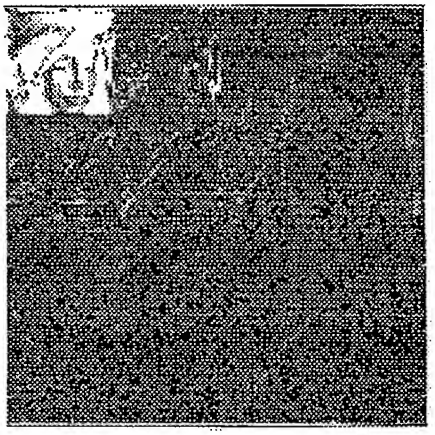

B101
VERTICAL ORIENTATION SUB - IMAGE
B111
DIAGONAL ORIENTATION SUB - IMAGE
B201
B211
B210
B301
B311
B300
B310
B110
HORIZONTAL ORIENTATION SUB - IMAGE

FIG. 3

400

FIG. 4



500

FIG. 5

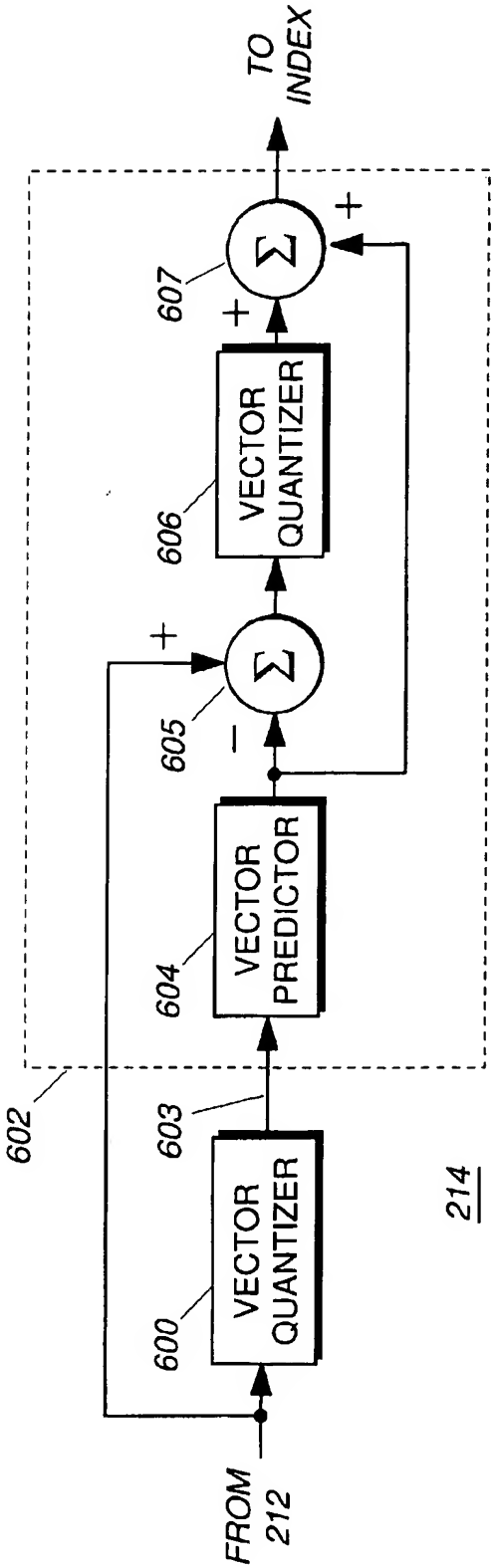

TO INDEX
607
Σ
+
+
606
VECTOR QUANTIZER
605
Σ
+
−
604
VECTOR PREDICTOR
603
600
VECTOR QUANTIZER
602
214
FROM 212

FIG. 6

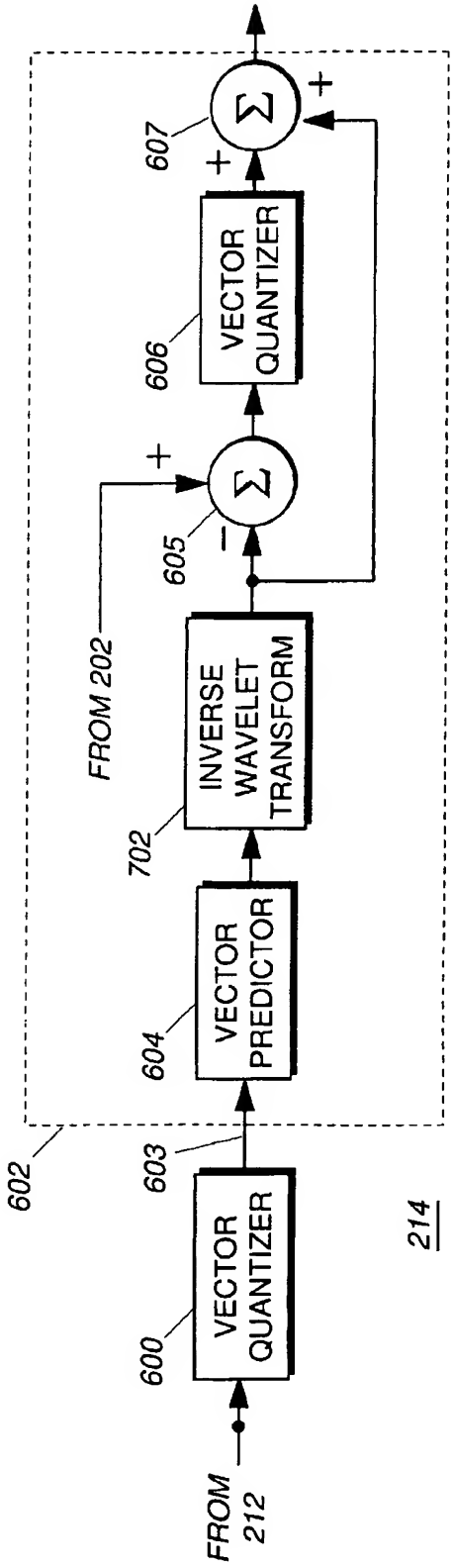

FROM 212
600
VECTOR QUANTIZER
603
604
VECTOR PREDICTOR
702
INVERSE WAVELET TRANSFORM
FROM 202
605
606
VECTOR QUANTIZER
607
602
214

FIG. 7

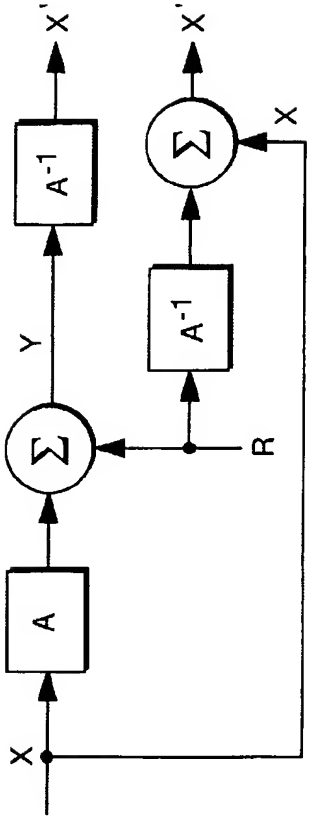

X
A
Y
Σ
R
A-1
A-1
X'
X'
X

FIG. 8

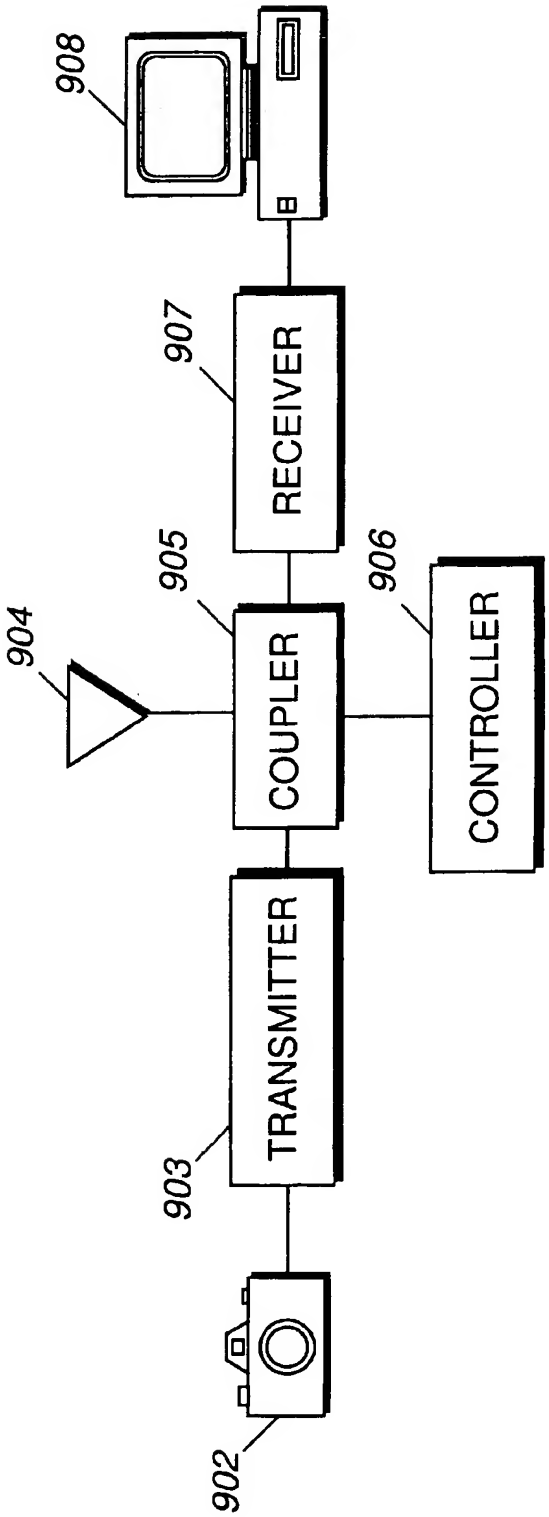

908
907
RECEIVER
905
906
904
COUPLER
CONTROLLER
TRANSMITTER
903
902
900

FIG. 9

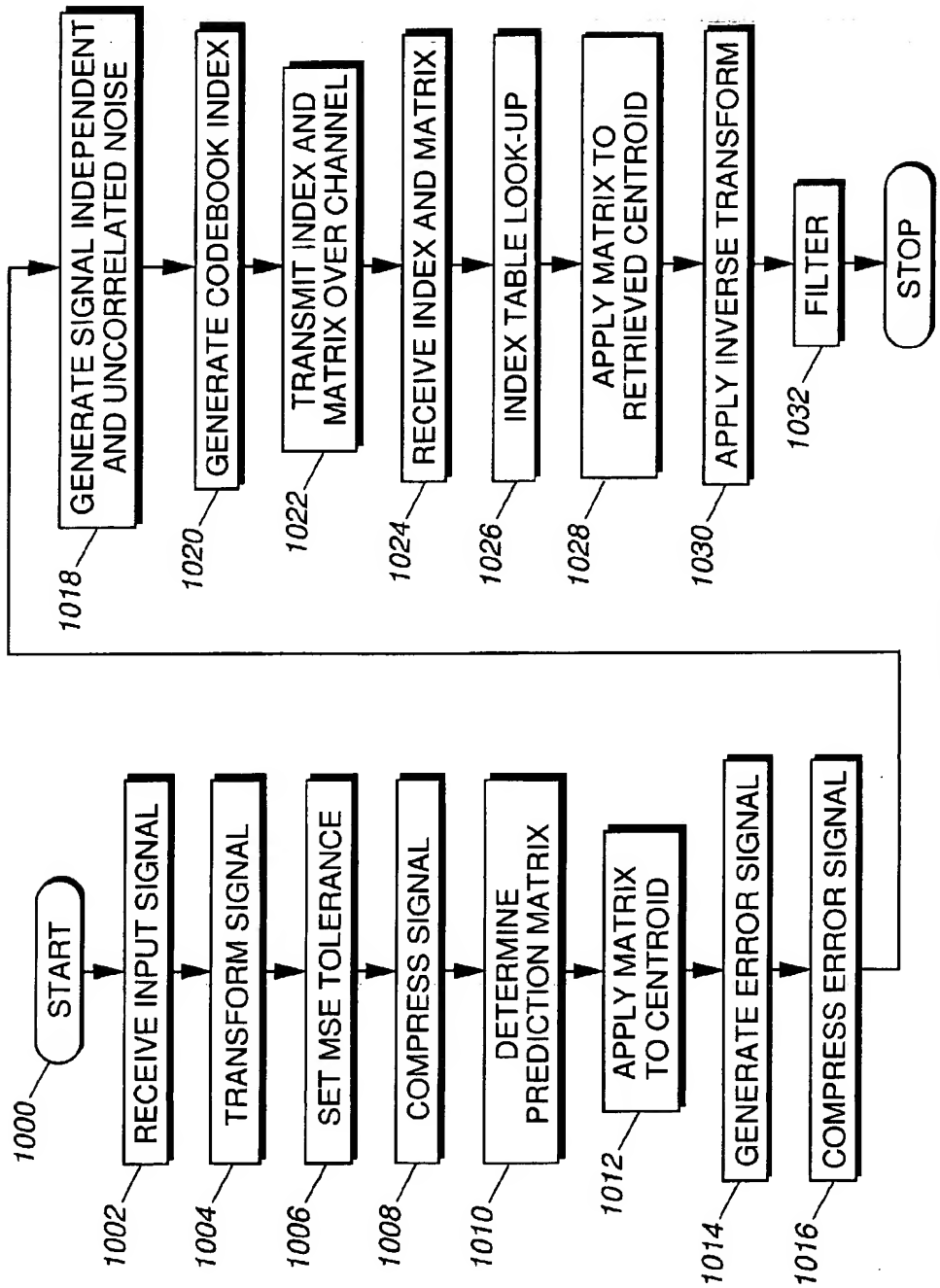

START
1000
RECEIVE INPUT SIGNAL
1002
TRANSFORM SIGNAL
1004
SET MSE TOLERANCE
1006
COMPRESS SIGNAL
1008
DETERMINE PREDICTION MATRIX
1010
APPLY MATRIX TO CENTROID
1012
GENERATE ERROR SIGNAL
1014
COMPRESS ERROR SIGNAL
1016
GENERATE SIGNAL INDEPENDENT AND UNCORRELATED NOISE
1018
GENERATE CODEBOOK INDEX
1020
TRANSMIT INDEX AND MATRIX OVER CHANNEL
1022
RECEIVE INDEX AND MATRIX
1024
INDEX TABLE LOOK-UP
1026
APPLY MATRIX TO RETRIEVED CENTROID
1028
APPLY INVERSE TRANSFORM
1030
FILTER
1032
STOP

FIG. 10

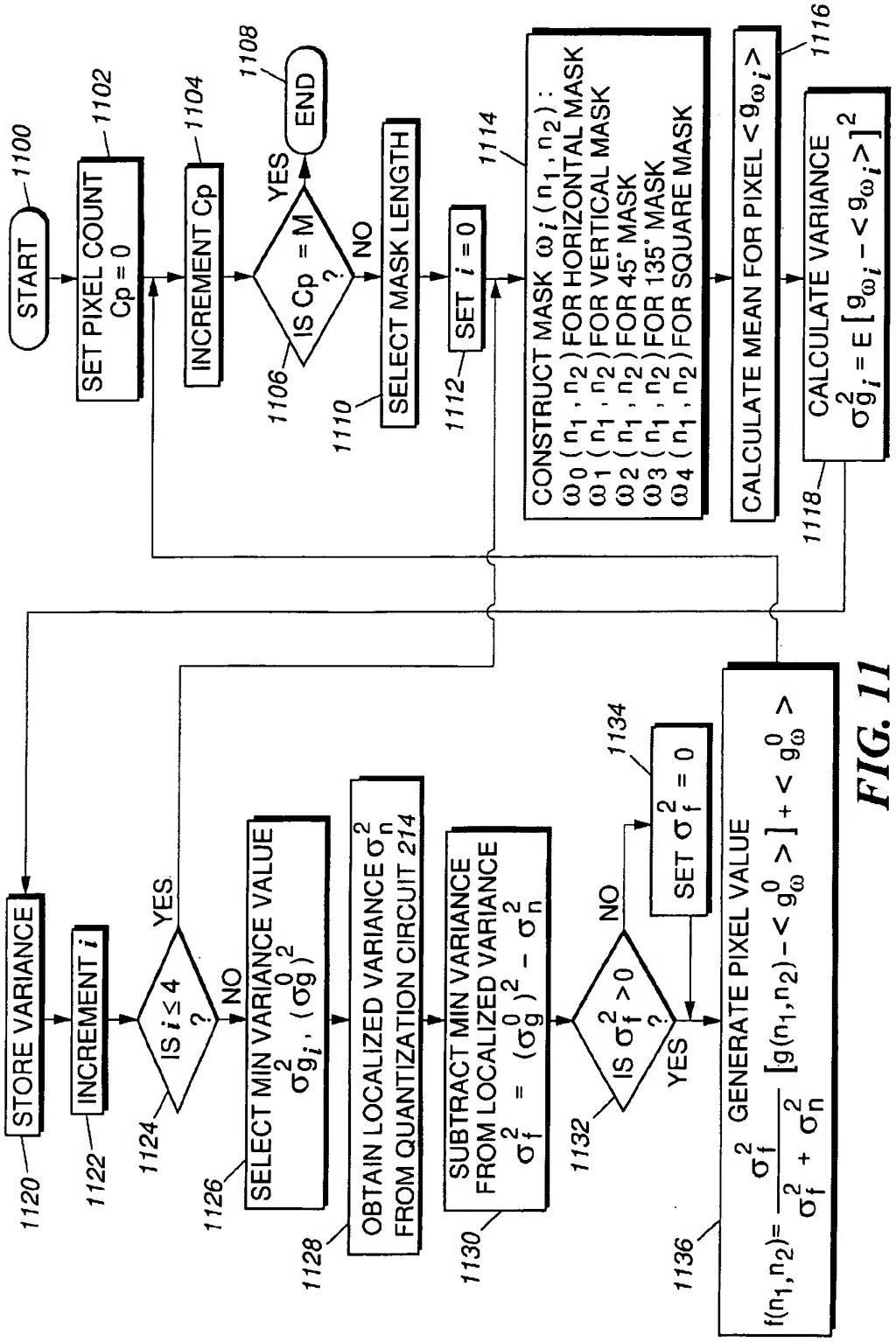

START
1100
SET PIXEL COUNT Cp = 0
1102
INCREMENT Cp
1104
IS Cp = M ?
1106
YES
END
1108
NO
SELECT MASK LENGTH
1110
SET i = 0
1112
CONSTRUCT MASK ωi (n1, n2):
ω0 (n1, n2) FOR HORIZONTAL MASK
ω1 (n1, n2) FOR VERTICAL MASK
ω2 (n1, n2) FOR 45° MASK
ω3 (n1, n2) FOR 135° MASK
ω4 (n1, n2) FOR SQUARE MASK
1114
CALCULATE MEAN FOR PIXEL <gωi>
1116
CALCULATE VARIANCE
σ2gi = E[gωi - <gωi>]2
1118
STORE VARIANCE
1120
INCREMENT i
1122
IS i ≤ 4 ?
1124
YES
NO
SELECT MIN VARIANCE VALUE
σ2gi, (σg0)2
1126
OBTAIN LOCALIZED VARIANCE σ2n FROM QUANTIZATION CIRCUIT 214
1128
SUBTRACT MIN VARIANCE FROM LOCALIZED VARIANCE
σ2f = (σg0)2 - σ2n
1130
IS σ2f > 0 ?
1132
NO
SET σ2f = 0
1134
YES
GENERATE PIXEL VALUE
f(n1,n2) = σ2f / (σ2f + σ2n) [g(n1,n2) - <g0ω>] + <g0ω>
1136

FIG. 11

1200

FIG. 12
(PRIOR ART)

1300

FIG. 13

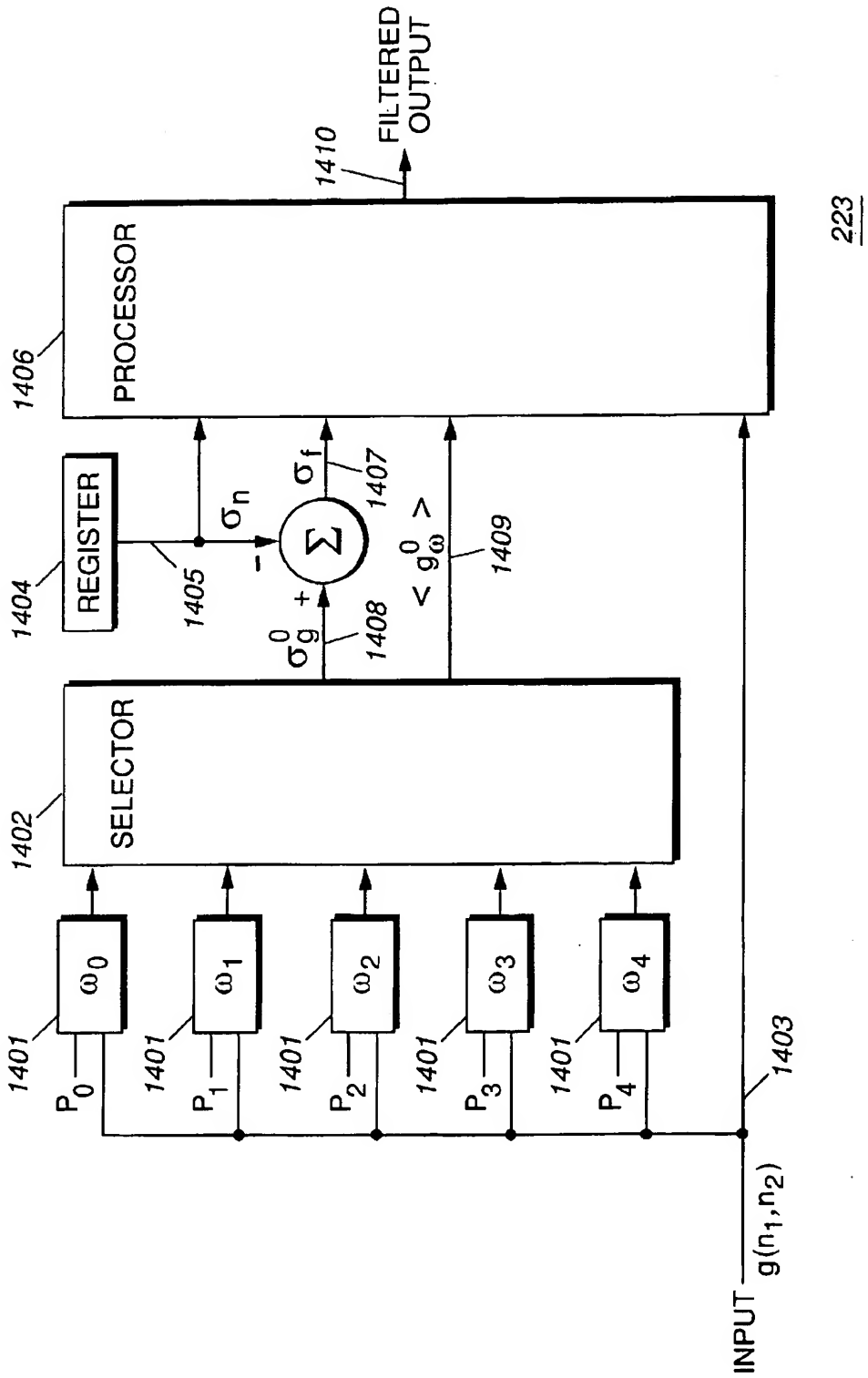

FILTERED OUTPUT
1410
PROCESSOR
1406
REGISTER
1404
1405
σ_n
σ_f
1407
Σ
$< g_\omega^0 >$
1409
σ_g^0
1408
SELECTOR
1402
ω_0
ω_1
ω_2
ω_3
ω_4
1401
P_0
P_1
P_2
P_3
P_4
1403
INPUT $g(n_1,n_2)$
223

FIG. 14

DATA COMPRESSION SYSTEM, METHOD, AND APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to U.S. application Docket No. CM02286J, by Yolanda Prieto, entitled "Adaptive Filtering for Use with Data Compression and Signal Reconstruction," filed concurrently herewith, and assigned to Motorola, Inc.

TECHNICAL FIELD

This invention relates in general to data compression and particularly to digital data compression. Specifically, the invention relates to a method, and apparatus that provides adaptive filtering in digital data compression system, such as, for example, slow rate video processing and other data compression applications.

BACKGROUND

With the advent of technologies and services related to teleconferencing and digital image storage, considerable progress has been made in the field of image processing. As will be appreciated by those skilled in the art, image processing typically relates to systems, devices, and methodologies for generating image signal data, compressing the image signal data for storage and/or transmission, and thereafter reconstructing the original image from the compressed image signal data. Critical to any highly efficient, cost effective image processing system is the methodology used for achieving compression.

As is known in the art, image compression refers to the steps performed to map an original image into a bit stream suitable for communication over a channel or storage in a suitable medium. Methodologies capable of minimizing the amount of information necessary to represent and recover an original image are desirable in order to lower computational complexity and cost. In addition to cost, methodologies capable of providing high quality image reproduction with minimal delay are likewise desirable.

Due to the enormous growth potential of businesses relying on these techniques, considerable work and effort has been conducted in this area. Despite these efforts, there still remains a need for an improved image processing method, system, and apparatus that operates to reduce the noise generated during image signal compression (quantization noise), improve the achievable signal to noise ratio (quality) during image reconstruction, while avoiding the lengthy delays typically associated with prior art approaches.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial block diagram of an image processing system known in the art.

FIG. **2** is a block diagram of the image processing system of the present invention

FIG. **3** is a graphical representation of the application of an image signal to the wavelet transform of FIG. **2**.

FIG. **4** is a pictorial representation of an original image.

FIG. **5** is a pictorial representation of the application of the image of FIG. **4** to the wavelet transform of FIG. **2**.

FIG. **6** is detailed block diagram of a first embodiment of the quantizer circuit of FIG. **2**.

FIG. **7** is detailed block diagram of a second embodiment of the quantizer circuit of FIG. **2**.

FIG. **8** is a functional block diagram of the predictor circuit as taught in accordance with FIGS. **6** and **7**.

FIG. **9** is a block diagram of a communications device of the type anticipated for use by the present invention.

FIG. **10** is a flow chart diagram depicting the steps performed by the device of FIG. **9** employing the compression methodology of the present invention.

FIG. **11** is a flow chart diagram depicting the steps involved with filtering noise in accordance with the present invention.

FIG. **12** is a pictorial representation depicting original image reconstruction in accordance with the prior art.

FIG. **13** is a pictorial representation depicting original image reconstruction in accordance with the present invention.

FIG. **14** is a functional block diagram of an embodiment of the filter of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

While the specification concludes with claims defining the features of the invention that are regarded as novel, it is believed that the invention will be better understood from a consideration of the following description in conjunction with the drawing figures, in which like reference numerals are carried forward. For the sake of clarity, the present discussion relates to a data processing system, method, and apparatus that employs an encoder optimized to decorrelate and make independent from an original signal, the quantization noise produced during signal compression. The proposed methodology supports high degrees of signal compression, which in turn leads to lower computational complexity and improved performance (i.e., reduced delay). Because the quantization noise produced during signal compression is made non-linearly independent from and orthogonal (i.e., uncorrelated) to the original signal, enhanced filtering techniques are required, which in turn will lead to improved signal-to-noise ratios (SNR) when compared to the known art. The present invention, therefore, is a method and apparatus for filtering data signals to remove independent and uncorrelated noise generated during data compression.

Referring now to FIG. **1**, a partial block diagram of a known data communications system **100** is shown. As will be appreciated, the communication system **100** depicts an encoder **110** coupled to a decoder **120** across a channel **130**. Both the encoder **110** and the decoder **120** employ compression. As is known, compression attempts to map an original signal into a bit stream suitable for communication over the channel **130**. The communications channel **130** may include a wireless, wireline, acoustic, or optically linked transmission path such as, for example, a radio frequency (RF) or fiber optic transmission path. The channel **130** may likewise be a storage medium such as those now known or later developed. Central to all systems of compression is the desire to reduce the number of bits required to represent and subsequently reproduce an original signal.

Since the communication system **100** of FIG. **1** is well known, minimal explanation will be provided at this time. The interested reader may nevertheless refer to P. C. Cosman, R. M. Gray, and M. Viterlli, "Vector quantization of image subbands: A survey," IEEE Transactions on Image Processing, vol. 5, no. 8, pp. 202–225, February 1996, for a more detailed discussion. Suffice it to say, however, the input **102** to system **100** is usually a sampled analog signal. When

the input **102** represents an image signal, the samples s(n) e.g., pixels, typically have a resolution of 8–12 bits per sample. The encoder **110** operates to reduce the number of bits per sample required to represent the sampled signal and meet the channel capacity requirements.

In operation, encoder **110** employs a decomposition encoder, such as, for example, a frequency domain encoder. Such an encoder, having M parallel subband filters **112** covering the complete frequency bandwidth of the input signal **102**, will encode each frequency band with a coder and at a bit rate matched to the statistics and relative perceptual importance of the particular frequency band in question. As will be appreciated by those skilled in the art, frequency domain encoding techniques offer the advantage that the number of bits used to encode each band can be variable, such that bands with little or no energy may not require encoding, resulting in improved compression. This methodology is frequently referred to as subband encoding.

Each subband filter **112** output is subsequently quantized (compressed) and coded by encoder **114** at a bit rate selected to reduce the number of bits required to represent each sample. There are several algorithms that may be used to achieve compression of an original signal. The most elementary methods quantize each signal sample into one of a small number of levels, each one thereafter being represented by a channel symbol from a global code book. As will be appreciated, a channel symbol need be nothing more than an index or pointer into the location of centroids within a code book. A well-known quantizer is the Lloyd-Max optimal quantizer using nearest neighbor, minimum squared error (MSE) rules to classify an input into a specified number of levels. Assuming the original signal is an image signal, the typical bit rate of an image with acceptable quality when compressed in this way is about 0.4 bits/pixel.

At the receiving end, decoder **120** will reconstruct the original signal. In accordance, decoder **120** has its own code book **124**, identical to the code book of encoder **110**. Assuming the encoder index is communicated across the channel **140**, the decoder **120** can retrieve respective channel symbols and/or code-vectors by merely indexing the code book **124** lookup with a received index. Thereafter, a synthesis filter bank made up of filters **122** receives upsampled-by-M or interpolated subband signals in order to reconstruction the original image samples s'(n). In the absence of quantization, the filters **112** and **122** are interdependent and designed in such a way as to permit perfect reconstruction of the original image **102**.

Again, a fundamental advantage of subband coding for data compression is that it transforms the signal into a domain which typically provides unequal energy patterns at the different subbands. This pattern may therefore be exploited to select the optimum coding algorithm which controls the bit allocation among the subbands, according to its energy or perceptual importance. In accordance, subbands with little energy may not be coded at all, resulting in immediate compression. Another advantage is that quantization noise in a particular subband is limited largely to the band of interest, and will not therefore spill over to the other bands.

FIG. **2** is a partial block diagram of a data communications system anticipated by the present invention. In accordance with the preferred embodiment, the communication system **200** of FIG. **2** is an image processing system. As depicted, the decomposition encoder **212** is a multilevel wavelet transform stage that receives the input signal **202**, a sampled image signal wherein each pixel has an 8–12 bit/sample resolution. The wavelet transform stage **212** produces a output comprising subband selected vector coefficients of the image signal, as discussed further in association with FIG. **3**. Referring back to FIG. **2**, wavelet transform stage **212** is coupled to a quantization encoder **214** to communicate the wavelet transformed version of the sampled input signals to the quantizer encoder **214** for further compression.

As will be appreciated by those skilled in the art, after further review hereof, quantization encoder **214** employs first and second quantization stages in order to compress the wavelet transformed signal received from wavelet transform stage **212**. As will be discussed in detail in association with FIG. **4**, the first quantization stage compresses the wavelet transformed signal and produces compression/quantization noise components, correlated to an non-linearly dependent upon the input signal **202**. The second quantization stage compresses an error signal difference between the wavelet transformed signal and an estimate of the quantization noise components to produce noise components independent from the image signal. The purpose of isolating such noise components; namely, those independent from the image signal, is to pursue aggressive filtering techniques that improve reconstructed signal quality, without negatively impacting the desired image signal components. This is especially important when short vector lengths and small code books are employed during image reconstruction.

The quantizer **214** output will be represented by channel symbols or centroids maintained in code book **215**. In accordance with the preferred embodiment, each centroid contained within code book **215** is assigned a binary index **216**. The index is what is communicated over or stored to channel **230**. As previously discussed, the channel **230** may include a wireless, wireline, acoustic, or optically linked path such as, for example, a radio frequency (RF) or fiber optic transmission path. The channel **230** may likewise be a storage medium such as those now known or later developed.

At the receiving end, decoder **220** employs a code book **225** and table lookup **224** to retrieve previously stored (i.e., trained) centroid information by indexing the table lookup **224** with received index information **216** to retrieve information stored in code book **225**. As will be appreciated by those skilled in the art, the system **200** is most efficient when code book **225** content is identical to the code book **215** content. Under the circumstance where a single device will transmit and receive information utilizing system **200**, the device code book is trained by quantization those images of interests. Upon completion, a single code book for use during transmission and reception of data is available.

The indexed output of table lookup **234** is communicated to an adaptive filter **223** which filters the code book output to remove unwanted noise. Thereafter, an inverse wavelet transform stage **222** operates upon the filtered signal to reconstruct the original signal samples s'(n). While the preferred embodiment suggests filtering the table lookup **224** output, it will be appreciated by those skilled in the art, after review hereof, that adaptive filtering, as described herein in greater detail in association with FIG. **11**, may alternatively be performed after the inverse wavelet transformation stage **222** or after the quantization stage **214** without departing from the spirit of the present invention.

While the suggested decomposition encoder **212** is a wavelet transform stage, it will be appreciated by those skilled in the art that other frequency domain encoders now know or later developed may be substituted therefore to

achieve acceptable performance. Well known frequency domain encoding techniques include, but are not limited to, fast Fourier transform (FFT), discrete cosine transform (DCT), discrete sine transform (DST), discrete Karhunen-Loeve transform (KLT), discrete Walsh-Hadamard transform (WHT), wavelet transforms (WT), and combinations thereof.

Prior to vector quantizing the wavelet transformed version of the sampled input signal, the signal must be arranged in vector form as depicted in FIG. **3**. Starting with the subbands for the three level wavelet transform, the process is described as follows. Assume the original image as shown in FIG. **4** is 256 by 256 pixels. The subbands associated therewith shall be labeled BX**00**, BX**01**, BX**10** and BX**11**, where X=1, 2, or 3. With reference to FIG. **3** it will be appreciated that band B**100** is decomposed into four bands B**200**, B**201**, B**210**, and B**211**. Band B**200** is further decomposed into four bands, bands B**300**, B**301**, B**310**, and B**311**. From the corresponding each level of bands can be blocked into corresponding square blocks such that there is an equal number of blocks for each level of bands. This makes the block size reduce geometrically by ½ from the previous level, until the last band is blocked in pixels of 1 by 1 pixel size.

For a level L wavelet transform, there are 3L+1 subbands. In accordance with the present example, there are therefore 10 subbands. In the current example where the original image of FIG. **4** is 256 by 256 pixels, band B1 is 128 by 128 pixels, band B2 is of 64 by 64 pixels, while band B3 is 32 by 32 pixels. For L=3, the respective block sizes per band are 4×4, 2×2, and 1×1 respectively. This structure is more clearly observed with reference to FIG. **5**, which is a pictorial representation of the output of the wavelet transform upon receipt of the original image of FIG. **4**. While the present embodiment is a 3 level wavelet transform, it will be appreciated by those skilled in the art that a number of levels less than 3 or greater than 3 can be employed by such a wavelet transform stage.

FIG. **6** is detailed block diagram of one embodiment of the quantizer circuit **214** of FIG. **2**. As will be appreciated, the quantizer circuit of the present invention comprises a first vector quantization compressor **600**, coupled to the wavelet transform **212** of FIG. **2**, for quantizing i.e., compressing the data components received from the wavelet transform **212**. In accordance with the preferred embodiment, the first quantization compressor **600** adaptively sizes groups of image vectors presented by the wavelet transform **212** and quantizes the image vectors within each group to establish a centroid for each group. The output from the first vector quantization compressor **600** is a signal comprised in part of quantization noise components correlated to and dependent upon the image signal and compressed vector coefficients. It will be appreciated by those skilled in the art that since the wavelet transform **212** of FIG. **2** performs subband transformation on some, but not necessarily all of the subbands of the input signal **202**, quantization compressor **600** likewise performs subband compression on some but not necessarily all input signal subbands. In fact, the system of the present invention is advantageously optimized to operate on subbands according to their energy level or perceptual importance to the original data or image **400** of FIG. **4**.

As previously mentioned, the first and second quantization compressors **600** and **606** are Lloyd-Max quantizers. Notwithstanding, the preferred embodiment, other quantization compressors may be substituted therefore; namely, vector quantizers, scalar quantizers, trellis quantizers, and mean-squared-error quantizers, just to name a few.

Continuing, a predictor circuit **602** is coupled to the quantizer **600** output **603**. The predictor **602** operates to estimate, predict, or determine the quantization noise as generated by the first quantization compressor **600**. This output **603**, approximates the noise generated by the quantization compressor **600**. Because it is an estimate, as determined by vector predictor **604**, it will not typically share a phase relationship or correlation to the input signal **202** of FIG. **2**, and may therefore be used as the uncorrelated noise component of the quantizer **600**. In effect, predictor **602** operates to decorrelate the noise generated by quantizer **600** from the input signal **202** of FIG. **2**.

For a detailed block diagram of vector predictor **604**, the interested reader may refer to FIG. **8**. Vector predictor **604** employs a gain-plus-additive-noise model which operates as follows:

$$Y=Q[x]=X+E=AX+R \quad 1)$$

where X is the data signal, Y is the quantized data signal, E is correlated quantized noise, R is uncorrelated quantized noise, and A is a prediction matrix.

The optimal value of the predictor matrix is:

$$A=(YX^t)(XX^t)^{-1} \quad 2)$$

To recover X multiply by the inverse of A:

$$A^{-1}Y=X+A^{-1}R=X+N \quad 3)$$

where N is uncorrelated with X, albeit non-linearly dependent on the input signal.

The error is determined as:

$$E+(A-I)X+AN=(A-I)X+R \quad 4)$$

Referring back to FIG. **6** the vector predictor **604** output; namely, the uncorrelated quantization noise components, are summed at summing junction **605** with the transformed output of the transform **212** of FIG. **2** to produce an error signal. Likewise, when the input signal is an image, it will be appreciate by those skilled in the art that the estimate signal generated by vector predictor **604** when summed with the plurality of image vector coefficients provided by the wavelet transform **212** of FIG. **2** will combine to generate an error signal. A second Lloyd-Max quantization compression stage **606** is coupled to the summing junction **605** for quantizing the error signal as generated by the summer **605** to generate a quantized error signal. Thereafter, the summing circuit **607** operates to sum the quantized error signal and the estimated signal to generate an output comprised in part of signal independent noise components that are uncorrelated to the input signal and code book content; namely centroids.

In accordance with the present invention, each centered as determined during data encoding is assigned a binary index. This index is typically what is communicated from the encoder **210** to the decoder **220** of FIG. **2**. Because the decoder **220** has a code book **225** typically identical to the code book **215** employed by the encoder **210**, the centroid values can be retrieved by means of indexing lookup table **224** via the received binary index. As will be appreciated by those skilled in the art, it is more economical and less complex to communicate an index **216** as opposed to actual centroid coefficients.

One of the more critical steps in vector quantization is the design of the code book, such that the operation of the decoder **220** is completely described once the code book is specified. Typically, the set of quantizer outputs describe the

code book and the process of placing these outputs is referred to as code book design. In accordance with the preferred embodiment, code book design employs the Linde, Buzo, and Gray algorithm, commonly referred to as the LBG algorithm. For additional details, the interested reader is referred to Y. Linde, A. Buzo, and R. M. Gray, "An algorithm for vector quantizer design" IEEE Trans. Comm., vol. COMM-28, pp. 84–95, 1980.

FIG. **7** is a detailed block diagram of a second embodiment of the quantizer circuit **214** of FIG. **2**. As will be appreciated after literal comparison, the circuits are virtually identical. Due to the close similarity, only the differences will be discussed at this time. With reference to FIG. **7**, an inverse wavelet transform stage **702** is employed at the output of vector predictor **604**. The inverse wavelet transform stage **702** operates to convert the vector predictor error estimate into an estimate image signal. Thereafter, the estimate image signal is summed at summing junction **605** with image signal **202** to produce an image error signal. The second Lloyd-Max quantization compression stage **606** is coupled to the summing junction **605** for quantizing the image error signal as generated by the summer **605** to generate a quantized image error signal. Thereafter, the summing circuit **607** operates to sum the quantized image error signal and the estimated image signal to generate an output comprised in part of signal independent noise components that are uncorrelated to the input signal. Upon closer inspection it will be appreciated by those skilled in the art that the primary differences between the teachings of FIGS. **6** and **7** are that FIG. **6** operates at the subband image level while FIG. **7** operates at the image level.

With reference to FIG. **9**, a block diagram of a communications device **900** of the type anticipated for use by the present invention is depicted. The communications device **900** employs a transmitter **903** which operates to transmit signals received from peripheral device **902**. For the purpose of this discussion, let's assume device **903** is a document scanner like those known in the art. A receiver **907** couples received signals to peripheral device **908**. For the purpose of this discussion, let's assume device **908** is a display device, such as, for example, a cathode ray tube (CRT), liquid crystal display (CRT), or any other type display device, now know or later developed and capable of presenting graphical, pictorial, or text based messages to a device user **900**. The antenna **904** of the present invention is coupled to the transmitter **907** and the receiver **907** through coupler **905**. As will be appreciated, coupler **905** provides switched operations between transmitter **903** and receiver **907** under the direction of controller **906**.

As will be appreciated by those skilled in the art after review hereof, the encoder **210** of FIG. **2**, when used in association with the device **900** of FIG. **9**, will typically be used during transmit mode. In a similar fashion, the decoder **220** of FIG. **2**, when used in association with the device **900**, will typically be used during receipt.

FIG. **10** is a flow chart diagram depicting the steps performed by a device **900** of FIG. **9** employing the compression methodology of the present invention. Commencing at start block **1000** flow proceeds to block **1002** where the communications device **900** of FIG. **9** receives a signal, such as an image signal, from a peripheral device **902** in anticipation of transmitting information from transmitter **903**. From block **1002**, flow proceeds to block **1004** where the information signal is transformed by a transform stage. In accordance with the preferred embodiment of the present invention, this transform stage is a frequency domain transform. In particular, the transform associated with block **1004** is a multilevel wavelet transform which decomposes the input signal into a set of sub-images with different resolutions corresponding to different frequency bands (refer to FIG. **5**). The resulting image coefficients are then vector quantized (compressed) at block **1008** using a mean square error (MSE) tolerance as set at block **1006**. The MSE tolerance in accordance with the present invention is adaptive (i.e., adjustable) such that the size of the groups of image coefficients around which respective centroids are calculated and across which the mean square error tolerance is exercised may be sized in order to improve image reconstruction time, reduce image reconstruction cost, or enhance image reconstruction quality.

From block **1008** flow proceeds to block **1010** where the vector predictor of **604** of FIG. **6** determines a prediction matrix as a function of the compression noise generated by the quantization compressor **600** of FIG. **6**. In accordance with the preferred embodiment, vector predictor **604** utilizes a gain-plus-additive-noise model further described by $Y=X+E=AX+R$, where X is the input signal, Y is the quantized input signal, E is correlated quantized noise, R is uncorrelated quantized noise, and A is a prediction matrix. From block **1010**, flow proceeds to block **1012**, where the vector predictor **604** applies the prediction matrix to the centroid of each group of vector coefficients to generate an estimate signal. Of importance, the estimate signal as generated by vector predictor **604** has noise components that are uncorrelated and non-linearly dependent upon the input signal. This dependence between the noise components and the input signal renders typical noise rejection techniques ineffective. Notwithstanding, substantial noise rejection improvement could be achieved if the interdependence between the estimate signal and the input signal were removed. To achieve this goal the present invention employs the prediction circuit **602** of FIG. **6** for generating signal independent noise components that are uncorrelated to the input signal.

From block **1012**, flow proceeds to block **1014**, where the estimate signal and with the plurality of image vector coefficients are summed to generate an error signal. From block **1014** flow proceeds to block **1016** where the error signal is compressed (quantized) by a mean square error (MSE) quantizer **606** of FIG. **6**. In accordance with the preferred embodiment, the quantizer **606** is a vector quantizer. In particular, the vector quantizer of choice is a Lloyd-Max quantizer, which, as previously mentioned, compresses the error signal to generate a quantized error signal. At block **1018** the quantized error signal and the estimate signal are summed to generate signal independent noise components that are uncorrelated to the input signal, such that filtering becomes an viable noise rejection mechanism. As will be appreciated by those skilled in the art after review hereof, filtering may be employed at either the encoder **210** output, the decoder **220** output, or any point of advantage thereinbetween.

From block **1018**, flow proceeds to block **1020** where a code book index **216** of FIG. **2** is created for each of the centroids generated in accordance with block **1008** above. From block **1018**, flow proceeds to block **1022** where the transmitter **902** of FIG. **9** transmits the index **216** and predictor matrix over the channel **230** of FIG. **2**.

At block **1024**, a communications device, such as the device **900** of FIG. **9**, receives the transmitted index and predictor matrix information. At block **1026**, the device indexes the code book **225** of FIG. **2** with the received index information to retrieve predetermined centroid coefficients stored to the code book. At block **1028** the predictor matrix

is applied to the retrieved predetermined centroid coefficients to generate an output comprising modified code book information. At block **1030** the modified code book information is filtered utilizing filter **223** of FIG. **2**. As described hereinafter, filter **223** is an adaptive orientation wiener (AOW) filter that operates to remove the signal independent and uncorrelated noise from the retrieved code book value, after application of the matrix.

From block **1030**, flow proceeds to block **1032** where the inverse wavelet transform operates on the filtered signal to reconstruct the original signal samples s'(n). While the preferred embodiment suggests filtering the product output of table lookup **224**, it will be appreciated by those skilled in the art, after review hereof, that filtering may alternatively be performed after the quantization stage **214** as well as after the inverse wavelet transformation stage **222**.

FIG. **11** is a flow diagram depicting the steps performed by filter **223** of FIG. **2** as mentioned in association with step **1030** of FIG. **10** to provide filtering in accordance with the present invention. The filter of the present invention is a spatial domain uncorrelated Weiner or adaptive orientation Weiner (AOW). The AOW of the present invention operates to process each pixel of the input image (g n_1, n_2) develop a set of masks which when applied to the pixel will assist in reducing noise variance and more clearly defining image edges.

In operation, the filtering commences at start block **1100** when a code book output product is received by filter **223** of FIG. **2**. As will be appreciated the code book output comprises a plurality of coefficients, each coefficient comprising a signal component and a noise component. The noise component comprises signal independent uncorrelated noise. As will be appreciated from this continuing discussion, the input to filter **223** is typically a subset of the coefficients that comprise the entire image. From block **1100**, flow proceeds to block **1102** where a pixel counter C_p is set to zero. At block **1104** the pixel counter C_p is incremented. At block **1106** a check is made to determine whether all image pixels have been processed. If so, flow proceeds to block **1108** where the process flow terminates. Otherwise, flow proceeds from block **1106** to block **1110** where a mask length is selected. The mask length refers to a number of pixels around each pixel and is defined as 2p+1. From block **1110**, flow proceeds to block **1112** where the variable i is set to zero, 0. At block **1114**, one of a plurality of masks is generated. In accordance with the preferred embodiment, there are five to choose from; namely, the square filter, represented by $(2p+1)^2$ with the pixel at the center (n_1, n_2), the horizontal filter, with pixels (n_1−p: n_1+p, n_2), the vertical filter, with pixels (n_1, n_2−p: n_2+p), and the 45 degree filter, as well as the 135 degree filter. If we consider the rectangular window g (n_1−p: n_1+p, n_2−p: n_2+p) of pixels as a matrix W (n_1, n_2) of size (2p+1), the filter processes either 1) the entire matrix with the square filter; 2) the central row with the horizontal filter; 3) the central column with the vertical filter; 4) the second main diagonal with the 45 degree filter; or 5) the main diagonal with the 135 degree filter. As will be appreciated by those skilled in the art, the square filter is a low pass filter while the directionally oriented filters are edge detectors filters.

From block **1114**, flow proceeds to block **1116** where a mean is calculated for the pixel in question in accordance with

$$<^{s}\omega_i> \qquad 5)$$

From block **1118**, flow proceeds to block **1220** where a variance is calculated for the pixel in question in accordance with:

$$\Sigma_i\{(^{s}\omega_i-<^{s}\omega_i>)^2\} \qquad 6)$$

From block **1118** flow proceeds to block **1120** where the variance as calculated at block **1118** is stored. At block **1122** i is incremented. Thereafter, at block **1124**, a check is made to determine whether all masks under consideration have been applied. If not, flow branches back to block **1114** where a different mask is selected and the mean and variance are again calculated and stored for the pixel in question as differentiated by a second mask. This process continues until all masks in question have been used to generate means and variance data for the pixel in question.

After all the masks of interest have been applied, flow proceeds from block **1124** to block **1126**, where a minimum variance value is selected. Said another way, at block **1126** a filter mask from among the plurality of filter masks is selected. As will be appreciated by those skilled in the art, after review hereof, the filter mask exhibiting a minimum variance output is typically a mask having a directional orientation (e.g., horizontal, vertical, 45 degree, 135 degree) similar to the orientation exhibited by the group of image components being filtered. Thus, in accordance with the preferred embodiment, the filter **223** of FIG. **2** adaptively selects a filter mask from a plurality of available filter masks. Based, in part, upon similar or shared orientations between the mask and a group of image components. Of note, the above process need not require that all available masks be employed. It merely sets forth that some set of masks less than or equal to the set of available masks is satisfactory to perform the task.

From block **1126**, flow proceeds to block **1128** where a localized noise variance as determined by the quantization circuit **214** of FIG. **2**., passed across the channel **230** of FIG. **2**, and stored in memory is retrieved. At block **1130** the localized noise variance is subtracted from the minimum variance to generate an estimated local variance.

At block **1132** a check is performed to determine whether the estimated localized variance is greater than a threshold. If so, flow proceeds to block **1136**, otherwise, flow proceeds to block **1134** where the estimated localized variance is set to zero and then flow proceeds to block **1136**. At block **1136** a filtered pixel value can be estimated as a function of the estimated localized variance. As the image variance estimate improves over the noise level, the output value more closely resembles the original input. From block **1136** flow branches back to block **1104** where the pixel counter is incremented and the process is repeated. As will be appreciated by those skilled in the art, this process will continue until all pixels of the reconstructed image have been filtered. In accordance, the AOW of the present invention performs image reconstruction and filtering on a pixel-by-pixel basis with a mask length of (2p+1). The center pixel is associated with a specific centroid by the decoder and the value of the estimated noise variance is obtained by quantizer **214** of FIG. **2** and passed across the channel **23C** for use during image signal reconstruction and noise filtering as suggested herein.

The advantages of the present invention are several. Suffice it to say, however, the quantization circuit **214** of FIG. **2** permits one to degrade the original image by selecting fewer centroids over which to represent an original image, thereby reducing the size of the code book required to practice image reconstruction. Reduction in code book sizes typically equates to a faster image reconstruction system. Since the present invention elects to deal with the noise associated with compression, a recognizable improvement in signal-to-noise is exhibited by this approach which operates to render noise generated during data compression signal independent and uncorrelated from the input so that it may be filtered without negatively impacting the original input.

Filtering, as taught by the present invention, is directed towards the removal of independent and uncorrelated noise components from the reconstructed signal. In accordance, an adaptive filter selects a filter mask from a plurality of available filter masks. Mask selection is based, in part, upon a similar or shared orientation between the mask and a group of image components/coefficients within the reconstructed signal. Of note, image component processing is performed on a local (e.g., pixel-by-pixel or 2 pixel-by-2 pixel) basis as opposed to a global basis (e.g. across the entire image). Moreover, image component processing may be performed at either the subband signal or image signal level. The advantage over the known art is that the noise correlation does not become correlated with the input as masks are sequentially applied.

For the sake of clarity, FIG. **12**. is a pictorial representation depicting original image reconstruction in accordance with the prior art. FIG. **13**, by contrast, is a pictorial representation depicting original image reconstruction in accordance with the present invention. These two figures are presented so that a visual comparison can be made.

While the preferred embodiments of the invention have been illustrated and described, it will be clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions and equivalents will occur to those skilled in the art without departing from the spirit and scope of the present invention as defined by the appended claims. For example, in accordance with the anticipated operation, the filter **223** of the present invention will likely be implemented in a digital signal processor (DSP), microprocessor, micro-controller, or some other computer logic circuit either currently available or later developed that is capable of performing the procedure of FIG. **11**. It will therefore be appreciated by those skilled in the art that filter **223** is achievable as a hardware or firmware embodiment such as the one depicted in FIG. **14**.

With reference to FIG. **14**, there is shown a plurality of filter masks **1401**, each having a different orientation as described hereinabove. Each filter mask **1401** receives as an input a value P representing the mask length and a group of input signal coefficients $g(n_1,n_2)$, **1403**. Selector **1402** operates upon the filter mask outputs to select a filter that provides a minimum variance output. In operation, it will be appreciated that the mask which provides such a minimum variance output will have an orientation which is similar to the orientation exhibited by the input $g(n_1,n_2)$. In accordance, mask selection may be determined as a function of orientation as well as minimum variance.

As depicted, the selector output **1408**, which is a minimum variance value, is summed with the localized noise variance value **1405**, generated during quantization by the quantizer **214** of FIG. **2** and stored to register **1404**, to generate an estimated local variance value **1407**. Thereafter, processor **1406** utilizes the appropriate inputs to generate the filtered output **1410** in accordance with block **1136** of FIG. **11**.

What is claimed is:

1. A data compression encoder comprising:

a first quantizer, for receiving an input signal having data and compressing the data to generate compressed data and signal dependent noise;

a predictor, coupled to the first quantizer, for generating uncorrelated noise components generated by the first quantizer; and a second quantizer, coupled to the predictor, for quantizing a signal indicative of noise generated by the first quantizer, such that the encoder produces signal independent noise components that are uncorrelated to the input signal.

2. The encoder of claim **1** further comprising a filter for filtering the signal independent noise components that are uncorrelated to the input signal.

3. The encoder of claim **1** further comprising a transform stage coupled to the quantizer.

4. The encoder of claim **3** wherein the transform stage is a transform selected from the group consisting of frequency domain transforms, spatial domain transforms, and statistical domain transforms.

5. The encoder of claim **1** wherein the quantizer is a device selected from the group consisting of vector quantizers, scalar quantizers, trellis quantizers, and truncation quantizers.

6. The encoder of claim **1** wherein the predictor is a device selected from the group consisting of gain-plus-additive noise predictor, memory less predictor, high order, predictor, non-linear predictors, and predictors having memory.

7. The encoder of claim **1** wherein the data is selected from the group of information consisting of: speech, audio, video, and still images.

8. A data compression encoder comprising:

a transform stage for receiving an input signal having data and providing a transformed output in response thereto;

a first quantizer, coupled to the transform stage, for quantizing the transformed output, to generate compressed data and signal dependent noise; and

a second quantizer, coupled to the first quantizer, for quantizing a signal indicative of noise generated by the first quantizer,

such that the encoder produces signal independent noise components that are uncorrelated to the input signal.

9. The encoder of claim **8**, wherein the transform stage is selected from the group consisting of frequency domain transforms.

10. The encoder of claim **8**, wherein the transform stage does not transform all subbands within the input signal.

11. The encoder of claim **8**, wherein the first and second quantizers are means-squared quantizers selected from the group of consisting of:

vector quantizers

scalar quantizers; and

trellis quantizers.

12. The encoder of claim **8**, further comprising a predictor, coupled between the first and second quantizers, for estimating noise components that are uncorrelated to the input signal.

13. The encoder of claim **8** further comprising a filter for filtering noise components that are signal independent and uncorrelated to the input signal.

14. A data compression encoder for use in slow rate signal processing comprising:

a wavelet transform for receiving an input signal and providing a transformed output having vector coefficients;

a first quantizer, coupled to the wavelet transform, for selecting a group of vector coefficients to form a vector and quantizing the vector to generate compressed data and signal dependent noise;

a predictor, coupled to the first quantizer, for estimating noise components generated by the first quantizer; and

a second quantizer, coupled to the predictor and the first quantizer, for quantizing a signal indicative of noise components generated by the first quantizer,

such that the encoder produces signal independent noise components that are uncorrelated to the input signal.

15. The encoder of claim 14, wherein the first and second quantizer are Lloyd-Max quantizers.

16. The encoder of claim 14, wherein the predictor estimates quantization noise as a function of Y=X+E=AX+R, where X is the input signal, Y is the quantized input signal, E is correlated quantized noise, R is uncorrelated quantized noise, and A is a prediction matrix.

17. The encoder of claim 14, wherein the first quantizer sizes groups of image vectors to enhance image reconstruction quality.

18. The encoder of claim 14, wherein the first quantizer sizes groups of image vectors so as to improve image reconstruction time.

19. The encoder of claim 14, wherein the first quantizer sizes groups of image vectors so as to reduce image reconstruction cost.

20. The encoder of claim 14, wherein the first quantizer alters a number of centroids required to represent the input signal by selecting a means-squared error tolerance.

21. The encoder of claim 14, wherein the predictor predicts the noise components being uncorrelated to the image signal as a function of quantization gain plus additive noise.

22. The encoder of claim 14, further comprising a filter to remove signal independent noise components that are uncorrelated to the input signal.

23. A data compression system comprising:

a transmitter;

an image encoder coupled to the transmitter and having:

a wavelet transform for receiving an image signal and providing a transformed output comprised of image vectors,

a first vector quantizer, coupled to the wavelet transform, for adaptively sizing groups of image vectors and quantizing the image vectors within each group to establish a centroid for each group and an index for each centroid,

a predictor, coupled to the first vector quantizer, for determining noise components generated by the first vector quantizer as a function of a prediction matrix, said noise components being uncorrelated to the image signal, and

a second vector quantizer, coupled to the predictor and the first vector quantizer, for quantizing a signal indicative of noise components generated by the first vector quantizer,

the transmitter communicating index and prediction matrix across a channel; and a receiver;

an image decoder, coupled to the receiver, for receiving the index and the prediction matrix, the image decoder comprising:

a table lookup for indexing centroid information with the index,

an inverse wavelet transform, coupled to the table lookup, for reconstructing the image signal; and

a filter, coupled to the inverse wavelet transform, for filtering signal independent noise components that are uncorrelated to the input signal.

24. The system of claim 23, wherein the wavelet transform improves image signal compression by transforming select image signal subbands.

25. The system of claim 23, wherein the first vector quantizer selects the size of image vector groups to enhance image reconstruction quality, improve image reconstruction speed, and reduce image reconstruction cost.

26. The system of claim 23, wherein the channel is selected from the group media consisting of:

wireless communications channels;

optical communications channels;

wireline communications channels;

radio frequency (RF) communications channels; and

storage media.

27. The system of claim 23 wherein a quantizer obtains a local noise variance generated for each centroid centered.

28. The system of claim 27 wherein the transmitter communicates local noise variances across the channel.

29. A data compression method comprising the steps of:

compressing an input signal having data to generate compressed data and signal depended noise; and

processing the signal dependent noise to generate signal independent noise components that are uncorrelated to the input signal;

wherein the step of processing the signal dependent noise comprises the steps of:

applying estimated noise component to the compressed data to generate a signal comprised in part of noise components that are uncorrelated to and dependent upon the input signal;

summing the signal comprised in part of noise components that are uncorrelated to and dependent upon the input image signal and the compressed version of the input signal to generate an error signal;

compressing the error signal to generate signal independent noise components; and

summing the signal comprised in part of noise components that are uncorrelated to and dependent upon the image signal with the signal independent noise components.

30. A method for compressing an image signal comprising the steps of:

receiving the image signal;

transforming selective subbands of the image signal into a signal comprising a plurality of image coefficients;

adaptively sizing groups of coefficients to form image vectors;

compressing the image vectors within each group with a vector quantization compressor to establish a centroid for each group;

estimating a compression noise as generated by the vector quantization compressor;

applying the compression noise estimate to the centroid for each group to generate an estimate signal comprised in part of noise components, uncorrelated to and dependent upon the image signal and estimated code vector coefficients;

summing the estimate signal and the plurality of image vectors to generate an error signal;

quantizing the error signal to generate a quantized error signal;

summing the quantized error signal and the estimate signal to generate an output comprised in part of signal independent noise components that are uncorrelated to the input signal; and

filtering the signal independent noise components.

31. The method of claim 30, wherein the step of transforming selective subbands of the image signal further comprises the step of:

selecting image signal subbands as a function of an original image; and

wavelet transforming the selected image signal subbands.

32. The method of claim 30, wherein the step of transforming selective subbands of the image signal further comprises the step of:

omitting image signal subbands as a function of the original image; and

wavelet transforming the selected image signal subbands.

33. The method of claim **30**, wherein the step of transforming selective subbands of the image signal further comprises the step of:

selecting low frequency image signal subbands for quantization.

34. The method of claim **30**, wherein the step of adaptively sizing groups of image coefficients further comprises the steps of:

selecting a small group of image vector to enhance image reconstruction quality; and

selecting a large group of image vectors to improve image reconstruction speed.

35. The method of claim **30**, wherein the step of adaptively sizing groups of image coefficients further comprises the step of:

adjusting the size of a group of image vectors to enhance image reconstruction quality, improve image reconstruction speed, and reduce image reconstruction cost.

36. The method of claim **30**, wherein the step of compressing the image vector within each group further comprises the step of:

selecting a code vector within a group; and

performing a mean-squared-error calculation between the selected code vector and all other image vectors within the group to establish the centroid for the group.

37. The method of claim **30**, wherein the step of estimating the compression noise further comprises the step of determining a predictor matrix.

38. A method for compressing an image signal comprising the steps of:

receiving the image signal and providing a transformed output thereof comprising a plurality of image coefficients;

adaptively sizing groups of image coefficients to form vectors and compressing vectors within each group to establish a centroid for each group;

determining a prediction matrix as a function of compression noise;

applying the prediction matrix to the centroid for each group to generate an estimate signal,

summing the estimate signal with the transformed output to generate an error signal;

compressing the error signal to generate a quantized error signal;

summing the quantized error signal and the estimate signal to generate signal independent noise components that are uncorrelated to the input signal, and modified centroid;

generating a code index;

communicating the code index and the predictor matrix across a channel;

receiving the code index and the predictor matrix from the channel;

indexing a lookup table via the code index to access a predetermined centroid;

applying the predictor matrix to the predetermined centroid coefficients to generate an output;

applying an inverse transform to the output to reconstruct the image signal; and

adaptively filtering the image to generate a reconstructed image.

39. The method of claim **38** further comprising the step of adaptively filtering the signal independent noise components that are uncorrelated to the input signal.

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